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Restricted energy loss model in ultraheavy nuclei charge detection with SSNTD

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Abstract The response characteristics of Lexan Polycarbonate detector has been investigated in the case of ultraheavy nuclei abundance in primary cosmic rays. The present investigation is based on a 5 6 years satellite exposure of lexan plastic to primary cosmic rays The lexan plate exposed are duly etched and scanned using a computerised image analyser

The response parameter of a solid state nuclear track detector is the ratio V_t/V_G which can be estimated from the measurable parameters major axis (D_A) and minor axis (D_B) of elliptic track signature in the plastic The response parameter in plastics, normally, is a function of the Restricted Energy Loss (REL) model of Benton But here we directly used the measurable parameter D_A as the charge response which is unconventional and have justified its application

Keywords Charge response, lexan polycarbonate, UH cosmic ions

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1. The experiment

The lexan detectors were exposed to primary cosmic rays for a period of about five years eight months in space. Such Solid State Nuclear Track Detector (SSNTD) stacks were consisting of 70 lexan polycarbonate sheets of thickness of 0.025 cm each and of total thickness 5.6 g-cm^{-2} duly interleaved at intervals with lead sheets as velocity degraders. The detail of the calibration of the detectors has been reported earlier by Thompson *et al.* [1]. The 10 lexan plates from the top and other 10 plates from the bottom of the stacks were etched for long hour *viz.*, for 21 days in 6.25 N NaOH aqueous solution at 40° for the fast scanning and also for the easy identification of the penetrating ultra heavy cosmic nuclei candidates. The bulk etch rate V_g of the lexan detector has been found to be 0.152 μm per hour. The geomagnetic cut-off energy over the detector orbit has rejected the galactic cosmic nuclei of energies below 1.5 GeV/n ($\beta \sim 0.92$).

The major and minor axes of the over etched pits are measured by using a transmitted light Hund optical microscope fitted with a digitised camera for computer measurements. The least count of the length measurement is 0.78 micrometer.

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2. Track registration is SSNTD

The discovery of track storing capacity of some polymers provided us an easy access to particle tracks. When a charged particle passes through polymers it creates an electrostatic imbalance along its path by breaking the polymer bonds. Then free electrons, radicals and ions will go to the interstitial places in immediate surroundings along the particle track. Obviously the damaged portion of the solid is thus full of ions and becomes chemically more active to some suitable chemical reagents, preferably ionic compounds to restore charge stability. The reagent also must be capable of etching the detector material in general and thus called etchant for processing an SSNTD.

The degree of radiation damage is greatest in the immediate vicinity of the particle trajectory and the etch rate has its greatest value V_T, called the track etch rate. The etch rate decreases as the distance from the trajectory increases. At a certain distance, the degree of damage falls off to some small value V_G and is called the general etch rate of the undamaged material. The ratio V_T/V_G is called the response parameter of an SSNTD.

Restricted energy loss (REL) model :

According to Henke and Benton [2] the response parameter in plastics, normally, is a function of the Restricted Energy Loss Rate. A heavy charged particle during its passage through matter, loses its energy predominantly in collisions with atomic electrons. The rate of energy loss is a function of the particle charge Z, its velocity β and the nature of the stopping material.

For a given particle, the distribution of the deposited energy is a function of distance from the particle trajectory and depends largely on the velocity of the particle. A low velocity particle looses energy through low energy collisions, and then that energy remains confined to a small cylindrical volume about the particle trajectory. But when fast particles collide with the medium, as in the case of exposure of plastic detectors to relativistic cosmic ions, a major fraction of its energy goes into the production of high energy recoil electrons (commonly known as high energy δ-ray).

These high energy electrons, which can have ranges of several millimeters (~ 10^{-3} m), are produced collinearly with the incident particle trajectory but tend to be scattered and thereby deposit energy over a considerable distance from the path of heavy ion. Since the thickness of the polymer detectors used in practice are often several micrometers (~ 10^{-4}), most of the energetic δ-rays are lost from the detector. So it is quite reasonable to assume that this energy does not play the deciding role in the process of track registration in SSNTDs and the total rate of energy loss dE/dx, should not be used as a rate of total energy deposition in the detector medium. Then the total energy loss rate dE/dx can be separated in two parts according to the energy loss due to close and distant collisions :

$$\frac{dE}{dx}=\left(\frac{dE}{dx}\right)_{\omega>\omega_0}+\left(\frac{dE}{dx}\right)_{\omega<\omega_0} \tag{1}$$

The distant collisions are defined as those resulting in the ejection of electrons of energy $\omega<\omega_0$, some predetermined value for the particular detector concerned. The energy ω_0

is such that, for close collisions the atomic electrons can be considered as free particles, while for distant collisions the incident heavy particle is treated as point charges [3].

The total rate of energy loss (dE/dx), originally given by Bethe and Bloch [3] is as follows :

$$\frac{dE}{dx}=\frac{2\pi n(z^*)^2 r_0^2 m_0 c^2}{\beta^2}\left[ln\frac{2m_0c^2\beta^2\gamma^2\omega_{max}}{I_{adj}^2}-2\beta^2-\frac{2C}{Z}-\delta\right], \tag{2}$$

where

n = density of electrons in the stopping material,

z* = effective charge of the ionizing material

$= z[1-exp(-125\beta/z^{2/3})]$,

$r_0 = e^2/m_0c^2$

= the classical radius of electron,

$\gamma = 1/(1-\beta^2)^{1/2}$,

I_{adj} = mean excitation potential of the detector material,

C/Z = tight binding shell correction,

δ = correction for the density effect.

The above equation has been separated in two parts by Henke and Benton [2] according to eq. (1). The rate of energy loss due to close collision [1st term of eq. (1)] is

$$\left(\frac{dE}{dx}\right)_{\omega>\omega_0}=\frac{2\pi n(z^*)^2 r_0^2 m_0 c^2}{\beta^2}\left[ln\frac{\omega_{max}}{\omega_0}-\beta^2\right] \tag{3}$$

and that due to distant collision [2nd term of eq. (1)] is

$$\left(\frac{dE}{dx}\right)_{\omega<\omega_0}=\frac{2\pi n(z^*)^2 r_0^2 m_0 c^2}{\beta^2}\left[ln\frac{2m_0c^2\beta^2\gamma^2\omega_0}{I_{adj}^2}-\beta^2-\frac{2C}{Z}-\delta\right]. \tag{4}$$

3. Results and discussion

As we have already discussed, in polymer detectors, the energy loss due to distant collision is only responsible for breaking of polymer bonds along the particle trajectory and is called the Restricted Energy Loss (REL).

Now it is seen that the response parameter V_T/V_G is normally a monotonically increasing function of REL rate *i.e.* $(dE/dx)_{\omega<\omega_0}$. The ratio V_T/V_G can be estimated from the measurable parameters major axis (D_A) and minor axis (D_B) of elliptic track signature in the plastic. But here we directly used the measurable parameter D_A as the charge response which is unconventional.

In the present experiment, the lexan detectors used to detect relativistic ultra heavy cosmic ray nuclei since the threshold $Z/\beta = 57$ for Lexan polycarbonate. Here $\omega_0 = 1000$ eV [1].

The measured major axis of the elliptic etch pit D_A when plotted against the $\left(\frac{dE}{dx}\right)_{\omega < \omega_0}$, exhibit a sensitive fit which obeys the form

$$D_A = 1.54947 \times 10^{-} \left(\frac{dE}{dx}\right)^{2.17017}_{\omega > \omega_0}, \tag{5}$$

this form is more sensitive than the conventional relation

$$D_A = 1.086 \times 10^{-6} \,(REL)^{2.14003}, \text{ where REL} = \left.\frac{dE}{dx}\right)_{\omega > \omega_0} \tag{6}$$

shown in Figure 1.

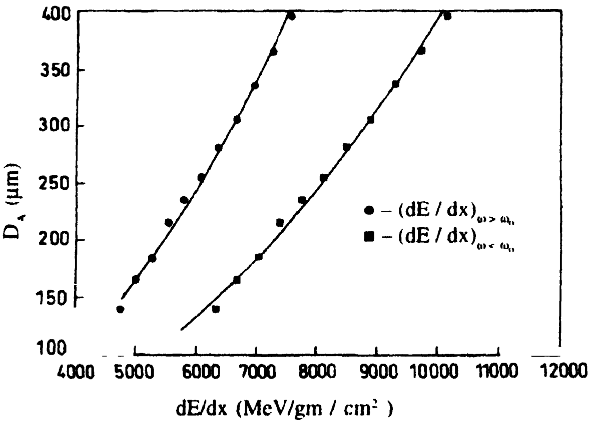

Figure 1. Comparative study of charge sensitivity of major axis on $(dE/dx)_{\omega > \omega_0}$ and $(dE/dx)_{\omega < \omega_0}$

So, it has been found that major axis of the elliptical tracks is more sensitive to $(dE/dx)_{\omega > \omega_0}$ and it seems that Lexan responds to only close collisions of δ-rays.

In the REL model [2], it is assumed that knock-on electrons with energy greater than ω_0 are ineffective in creating the permanent radiation damage which is the primary track. This assumption is supported by the observation that fission-fragment primary track diameters are less than $100 A^{\circ}$ in plastic [4]. Shirk and Price [5] and Fowler [6] have used the primary ionization model described by Price and Fleischer [7] with constant K set to infinity to analyze ultra heavy cosmic ray data. This approach assumes that a particle track property is determined solely by (Z^*/β). The data presented by O'Sullivan *et al* [8] with accelerators beams of ^{20}Ne and ^{28}Si ions and cosmic ray ^{56}Fe ions, in the log [REL] *versus* log [V_T] plot, ruled out the REL model, since he found a good calibration when etch rate V_T has been plotted against (Z^*/β).

The track etching rate V_T depends on Z and β only through the relation [8]

$$V_T = B[J(Z, \beta)]^n, \tag{7}$$

where

$$J(Z,\beta) = 10^{-4}\left[\frac{Z^{*2}}{\beta^2}\right] x\, ln\left[\beta^2/(1-\beta^2)\right] + K - \beta^2 - \delta(\beta), \tag{8}$$

with

$$Z^* = Z\left[1 - exp(-130\beta / Z^{2/3})\right]$$

and $\delta(\beta)$ is a parameter that takes into account the polarization of the medium.

In the present case with major axis as a charge response parameter we plotted its dependence against the Ionization Rate $J(Z, \beta)$ and found a more sensitive variation (Figure 2).

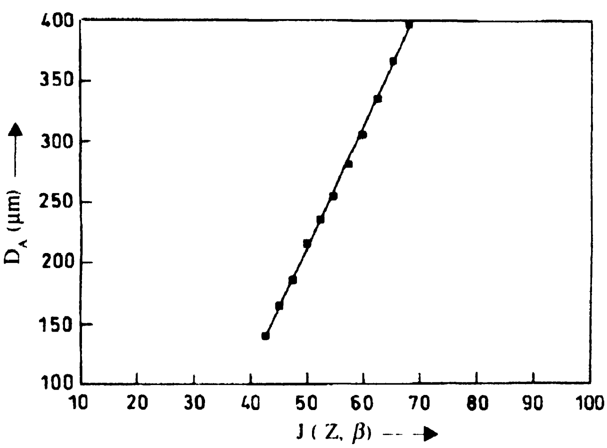

Figure 2. Major axis *versus* Ionization Rate Curve

The least square fitted curve shown in Figure 2 follows the relation

$$D_A = 9.9235 \times J(Z,\beta) - 284.131 \tag{9}$$

4. Conclusion

The charge sensitivity of a solid state nuclear track detector is related directly to the Total Ionization rate than the Restricted Energy Loss rate. Any measurable parameters of an etched track in SSNTD like major axis can be used as charge response of the detector instead of the conventional charge response V_T / V_G.

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